

SPATIO-TEMPORAL DYNAMICS OF MANGROVE COVER 1985-2025 BASED ON GEOSPATIAL ANALYSIS IN REMBANG

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Abstract

Mangroves are coastal vegetation that lives in tidal zones, providing ecosystem services such as biota habitats, abrasion barriers, breakbreaks, and significant carbon sequestration for climate change mitigation. However, the mangrove ecosystem in Indonesia, including in Rembang District, which includes Pasarbanggi, Tireman, and Kabongan Lor Villages, has been degraded due to land conversion into ponds, logging, and reclamation. This study aims to analyze the spatio-temporal dynamics of mangrove cover in 1985-2025 in Rembang District using MVI based on Landsat 5 (1985, 1995), Landsat 7 (2005), and Sentinel-2A (2016, 2025) satellite imagery. The analysis was carried out with a composite of NIR, Green, and SWIR Bands, digitization, cropping, cover classification, and analysis of mangrove cover changes. The results of the study show that the area of mangrove cover has experienced very significant fluctuations. The period 1985–2005 was dominated by heavy degradation (-67.93%), while the period 2005–2025 recorded a very strong recovery of mangrove ecosystems (+339.56%), with the high cover class increasing from 17.39 ha to 27.40 ha. The success of rehabilitation and reduced land conversion have succeeded in restoring the area of mangrove forests while improving the quality of mangroves in Rembang District.

Keywords: *Spatio-temporal dynamics, Rembang, Mangrove, MVI, Remote Sensing*

INTRODUCTION

Mangroves are plants that live in the tidal zone between the land and the ocean. Mangroves provide ecosystem services, in the form of providing timber, biota habitats such as fish and crustaceans, abrasion barriers, breakwaters, currents, and storms in the area around the coastline, as well as carbon sinks and stores (Castillo et al., 2017; Nguyen and Nguyen, 2021). Mangroves play a major role in climate change mitigation due to their ability to absorb and store carbon is greater compared to forest ecosystems on land (Banerjee et al., 2020). However, mangroves often undergo dynamic changes due to natural factors such as abrasion, sedimentation, and anthropogenic activities such as land conversion for ponds and settlements. Indonesia has 2,953,398 ha of mangroves covering about 20% of the total global mangroves and 61.25% of the mangrove area in Southeast Asia (Blanton et al., 2024). The condition of mangrove forests in Indonesia is experiencing several pressures, both from natural and human factors (Rafidinal et al., 2022). Indonesia experienced degradation of mangrove areas reaching 182.91 ha in the 2009-2019 period (Arifanti et al., 2021). Based on the Decree of the Minister of Forestry of the Republic of Indonesia No. 594 of 2025 concerning the National Mangrove Map for 2024, the total area of mangroves in Indonesia reaches 3,440,464 ha.

Mangroves in Rembang District are spread across three areas, namely Pasarbanggi Village, Tireman Village, and Kabongan Lor Village. The mangrove area in Pasarbanggi Village is considered one of the best because of its relatively good sustainability thanks to rehabilitation efforts that have been carried out since the 1960s (Annas et al., 2013). According to Laraswati et al. (2020), in 2003 Tireman Village was 3,830 ha, in 2013 it experienced an increase in area of 13,321 ha, but in 2018 the mangrove area of Tireman Village decreased to 10,968 ha. Another study in Pasarbanggi by Soeprbowati et al. (2024) explained that mangroves that in the 1960s only had a cover of about 3 ha, but after several planting programs in 1973, 1988, and 2000 the area swelled to tens of hectares. Although rehabilitation has been going on for a long time, human activities are a pressure on the mangrove ecosystem in Rembang Regency. The main factor causing degradation is the massive conversion of mangrove land into salt and fish ponds in villages around mangrove areas. Other pressures are uncontrolled tree felling, coastal reclamation, plastic waste pollution, and industrial waste that can affect beach dynamics.

Evaluation and measurement of mangrove area is needed to assess the dynamic trend of mangrove area change in the coastal area of Rembang District. Remote sensing technology is used to facilitate spatio-temporal monitoring of mangrove forest dynamics (Nguyen and Nguyen, 2021). This study aims to analyze the spatio-temporal dynamics of mangrove cover in 1985-2025 in Rembang District based on geospatial analysis of digital processing of Landsat and Sentinel satellite images using the Mangrove Vegetation Index (MVI).

METHODOLOGY

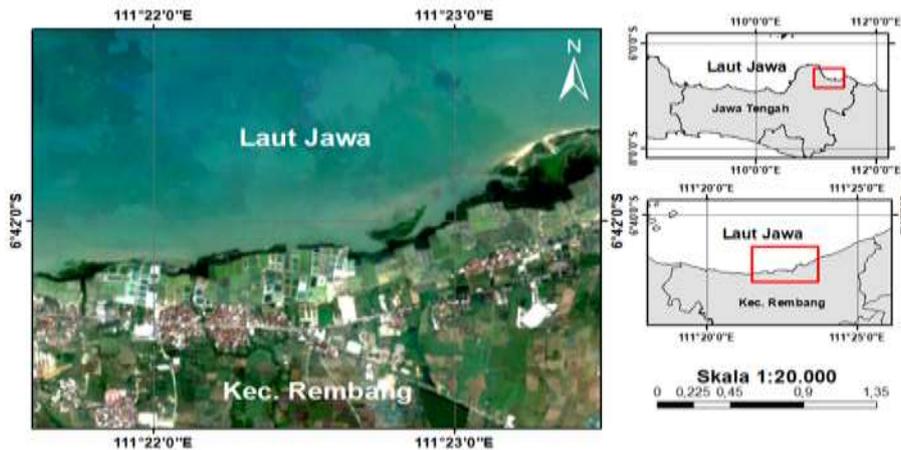


Figure 1. Research location.

The research location is located on the north coast of Central Java, precisely in the mangrove area of Rembang District which includes the villages of Pasarbanggi, Tireman, and Kabongan Lor as presented in Figure 1. Ground check data collection in mangrove and non-mangrove areas will be carried out in November 2025.

Data Collection

The satellite imagery data used includes Landsat 5 (1985, 1995), Landsat 7 (2005), and Sentinel-2A (2016, 2025), supported by conducting ground checks in mangrove and non-mangrove areas of Rembang District. The ground check data is taken using Garmin GPS 73 to record coordinate points. Satellite image data was collected and processed using Google Earth Engine (GEE) (Batubara et al., 2025). The imagery used is Landsat 5 for 1985 and 1995, Landsat 7 for 2005, and Sentinel-2A for 2016 and 2025. The images were composited using the median value of the image collection filtered using the Region of Interest (ROI) and a specific time span with a cloud cover tolerance of <20%. Geometry correction is already available on Sentinel-2A level products. The digitization process is used as a demarcation of the study area in potential mangrove zones.

Mangrove Vegetation Cover Analysis

Mangrove cover analysis was conducted using the Mangrove Vegetation Index (MVI) algorithm. MVI is a spectral index specifically developed to distinguish mangrove and non-mangrove vegetation, both terrestrial and aquatic vegetation (Baloloy et al., 2020). The MVI algorithm distinguishes the level of greenery and humidity between mangrove forests and land vegetation. MVI uses 3 bands, namely NIR, Green, and SWIR to distinguish mangroves and non-mangroves (Farahdillah et al., 2019). Mangrove vegetation cover was calculated using the MVI algorithm according to the following equation (Baloloy et al., 2020).

$$MVI = \frac{NIR - Green}{SWIR - Green}$$

Where:

NIR = Band Near-Infrared Radiation

Green = Band Green

SWIR = Band Short Wavelength Infrared

Mangrove cover maps are produced by setting thresholds at the MVI value. Baloloy et al. (2020) sets a minimum threshold value of 4.5 and a maximum of 16.5. This range of values has been able to separate the mangrove pixels from the terrestrial vegetation. This value is then divided into three classes of cover (Table 1) as follows.

Table 1. MVI value cap class	
Categories	MVI Value
Low	4.5 ≤ MVI < 6.5

Medium	$6.5 \leq MVI < 8.5$
Height	$MVI \geq 8.5$

Analysis of Mangrove Cover Changes

The mangrove cover data based on the MVI algorithm through GEE was further processed using ArcGIS software to analyze changes from two time periods (e.g., changes in 1985 and 1995, etc.). *Mangrove polygon layers* from two time periods were overlaid using the Union tool to analyze the change in cover. Determination of change categories using *Field Calculator (Python)* tools.

Accuracy Test

Accuracy tests or validation tests are carried out to assess the accuracy of interpretation results both digitally and with field data (Simmamora *et al.*, 2015). The accuracy test of the MVI classification results was carried out with *ground check* data in the form of 50 coordinate points (25 mangroves and 25 non-mangroves) collected using GPS in the field. These points are used to calculate the *overall accuracy* and *Kappa coefficient* through the *confusion matrix*.

RESULTS AND DISCUSSION

The study area includes Pasarbanggi, Tireman, and Kabongan Lor Villages, which are located in Rembang District, Rembang Regency, Central Java. This area is a coastal area with a mangrove ecosystem that is vulnerable to land conversion for salt ponds, fish ponds, and abrasion. Mangrove cover changes from 1985 to 2025 were analyzed using remote sensing that utilizes the MVI algorithm, which is an algorithm specifically designed to identify mangroves. Based on the area of mangrove cover and changes in mangrove area, as well as the graph of the dynamics of mangrove cover changes in 1985-2025 in Rembang District, it shows fluctuations in mangrove cover area.

Table 2. Mangrove area in 1985-2025 in Rembang District

Categories	Width (ha)				
	1985	1995	2005	2016	2025
Low	6,03	1,86	2,04	4,95	5,07
Medium	4,17	0,89	0,36	4,67	5,42
Height	16,68	6,74	6,22	17,39	27,40
Total (ha)	26,89	9,49	8,62	27,02	37,89

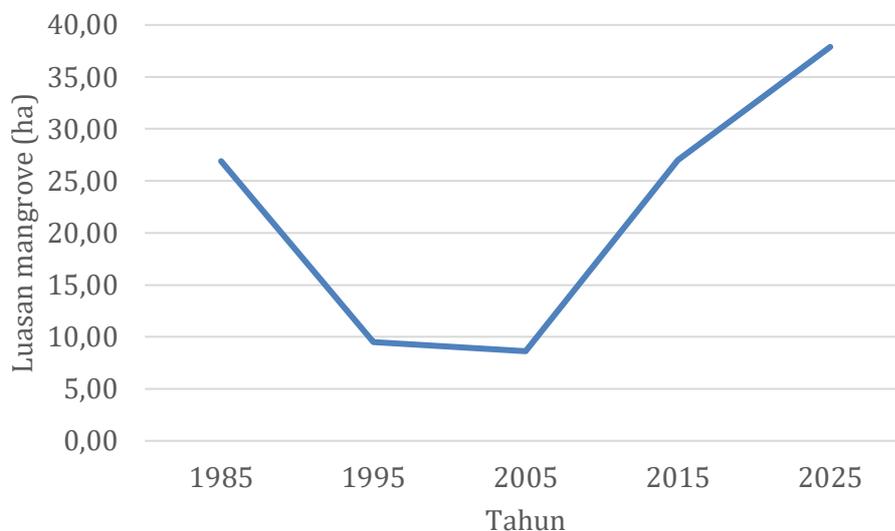


Figure 2. Dynamics of mangrove cover in 1985-2025 in Rembang District.

Table 2. Changes in mangrove area in 1985-2025 in Rembang District

Categories	Changes in Area (ha)
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	1985-1995	1995-2005	2005-2016	2016-2025
Additions	6,12	6,99	22,88	19,25
Fixed	3,37	7,86	4,14	19,33
Deduction	23,51	1,64	4,78	7,79

Period 1985-1995

In the period 1985-1995, mangrove cover experienced a very significant decline overall. The total area of the initial mangrove was 26.89 ha in 1985, then there was a decrease in area to 9.49 ha in 1995. This period was the heaviest phase of degradation over the last 40 years, with 87% of mangrove loss in just 10 years. This happened allegedly due to the conversion of mangrove land into massive salt ponds and fish ponds on the coast of Rembang Regency in the 1980s to 1990s. The increase in mangrove area in this period occurred only 6.12 ha in the 1980s.

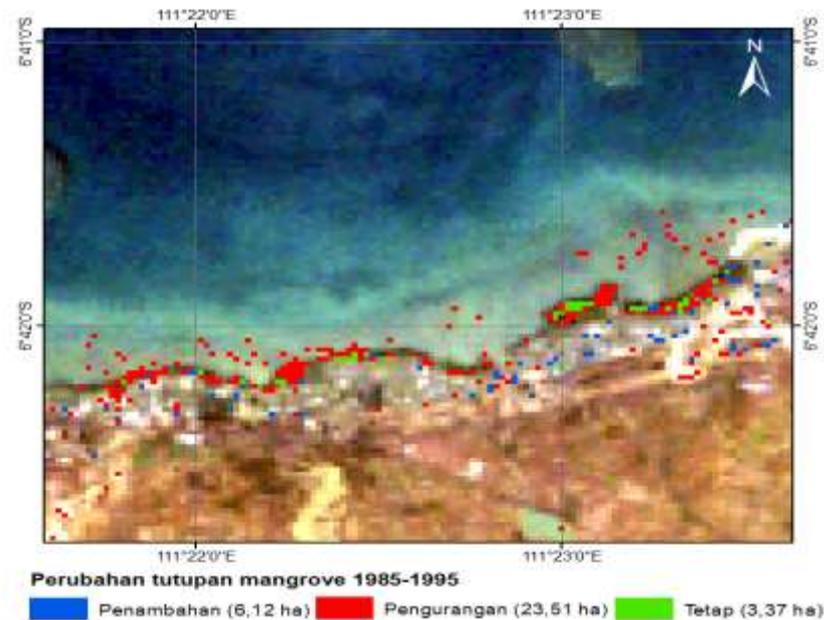


Figure 3. Changes in mangrove cover in 1985-1995 in Rembang District.

Period 1995-2005

Mangrove degradation continued during the period 1995-2005 (Figure 4). Although the rate of decline was slower compared to the previous period, there was a decrease in mangrove area from 9.49 ha (1995) to 8.62 (2005). The addition of mangroves is only 6.99 ha, close to the reduced area. Rehabilitation efforts, especially in Pasarbanggi that have been carried out since the late 1990s, have begun to detect images, but the recovery has not been strong enough to keep up with the ongoing land conversion.

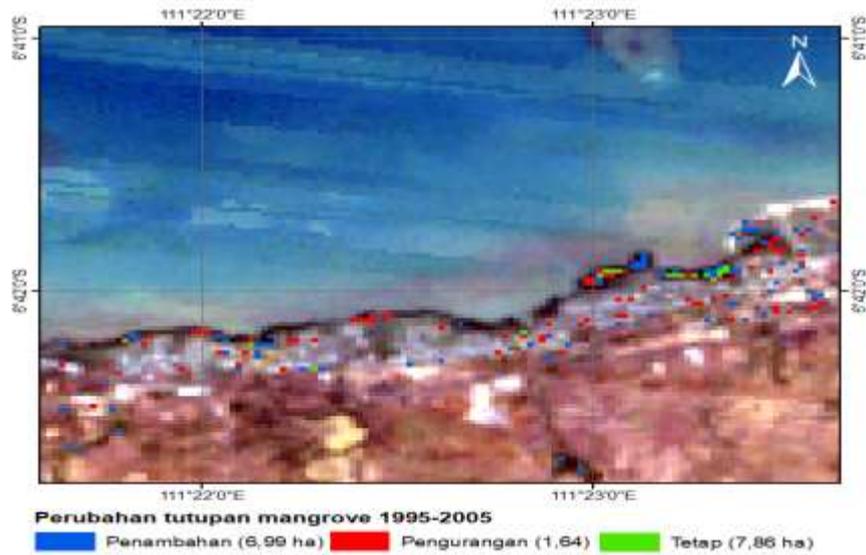


Figure 4. Changes in mangrove cover in 1995-2005 in Rembang District.

Period 2005-2016

In the 2005-2016 period, there was an increase in the area of mangroves up to 3 times, from an area of 9.49 ha in 2005 to 27.02 in 2016. The addition of 22.88 ha of mangrove area shows the existence of an intensive rehabilitation program, as well as a reduction in land conversion activities carried out by local communities in this period.



Figure 5. Changes in mangrove cover in 2005-2016 in Rembang District.

Period 2016-2025

The trend of mangrove area recovery continued in this period, although the increase in mangrove area was not as large as the previous period. The high cover class increased from 17.39 ha to 27.40 ha (+57%) which indicates an improvement in the quality and cover of mangrove vegetation (Figure 6). The increase in area of 19.25 ha is suspected to be the result of the post-2016 rehabilitation program.

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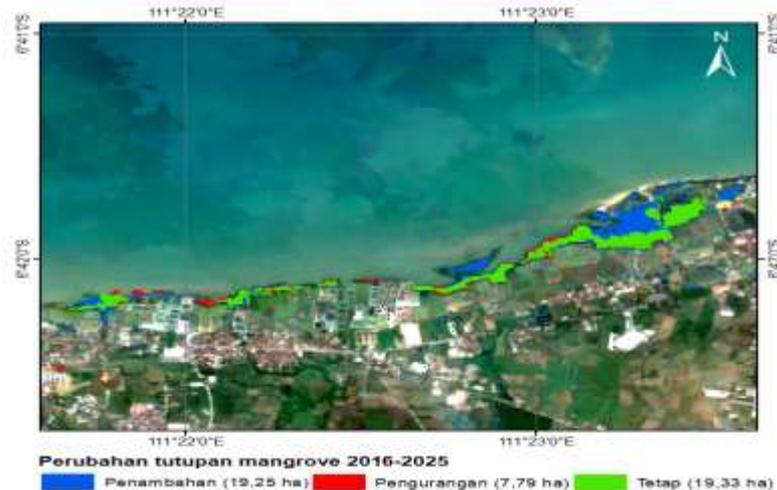


Figure 6. Changes in mangrove cover in 2016-2025 in Rembang District.

Rembang District is a northern coastal area in Rembang Regency, Central Java, which is one of the mangrove distribution areas, especially in Pasarbanggi, Tireman, and Kabongan Lor Villages. Along with the increase in the number of people living around Rembang District, this area is vulnerable to ecosystem damage and mangrove degradation (Mardliyah *et al.*, 2019). Changes in mangrove cover in Rembang District during the period 1985-2025 are influenced by interrelated natural and anthropogenic factors. Abrasion is one of the factors for changing mangrove cover in Rembang District. In addition, the conversion of land into aquaculture ponds also contributes to the degradation of mangroves in this region. The problem of damage to the mangrove ecosystem in the coastal area of Rembang Regency is caused by fish and shrimp cultivation activities in coastal areas, mangrove logging, reclamation, and sedimentation. A similar thing was conveyed by Ain *et al.* (2025), which explains that strategic issues along the coasts of Pasarbanggi, Tireman, and Kabongan Lor Villages are environmental degradation, abrasion, and pollution.

The spatio-temporal dynamics of mangrove cover in Rembang District during the period 1985-2025 show a "U-Shaped" pattern, namely heavy degradation in the first two decades followed by a very strong recovery in the last two decades. The area of mangroves in the first two decades (1985-2005) declined sharply. The cumulative impact of the conversion of mangrove land for salt and fish ponds was the main driver of the decline in mangrove area in 1985-2005 from 16.68 ha to 4.88 ha in the high cover class. This is in line with Melani *et al.* (2025) which states that more than 70% of mangrove damage in Rembang is caused by illegal aquaculture and logging activities. In contrast, explosive increases occurred in the last two decades, namely the period 2005-2016 (+246%) and the period 2016-2025 (+40%). This increase indicates that the mangroves that have been planted are starting to stabilize. This also illustrates the effectiveness of the national rehabilitation program and the active role of the Pasarbanggi community group who have planted and maintained mangroves since the 1960s until now. Recovery in 2005-2025 shows the positive impact of rehabilitation programs, with an increase in the middle and upper classes that reflect the adaptation of ecosystems to climate mitigation. This is reinforced by Azzahid *et al.* (2024) which states that the success of the rehabilitation program has restored the mangrove ecosystem in Pasarbanggi to a fairly healthy condition.

An increase in the high cover class can be an important indicator. The high cover class that increased (+461%) from 4.88 ha (2005) to 27.40 ha (2025) shows that rehabilitation in this region is not only successful quantitatively (extensive), but also qualitatively successful (ecosystem structure and function). This increase also shows that mangroves planted in the 2005-2016 period have reached the mature phase, are able to form a tight canopy, and provide full ecosystem services such as abrasion resistance, marine life habitat, and blue carbon sequestration. This is made clear by Soeprbowati *et al.* (2024), that the carbon stock in the restored mangrove ecosystem in Pasarbanggi is relatively higher than other restored mangrove areas in Indonesia. Pambudi (2023) showed that the mangrove species cover in this region is very high with the dominant species *Rhizophora mucronata*, *Rhizophora apiculata*, and *Avicenna marina*. The dominance of *Rhizophora* spp. ini caused by the condition of its mangrove ecosystem, which is largely the result of decades of restoration involving local communities with government support. In addition, *Rhizophora* spp. mangrove seedlings have a high survival rate and are relatively affordable, so this species is the main choice in rehabilitation and restoration activities. The involvement of stakeholders such as the government, non-governmental institutions, universities and the community has been quite good in Pasarbanggi (Joandani *et al.*,

2019). The mangrove replanting program by the Rembang Regency Environment Agency (DLH) is expected to increase the awareness of stakeholders regarding the importance of mangrove ecosystems as part of climate change adaptation and mitigation efforts in coastal areas (Azzahid *et al.*, 2020).

Table 2 . Test accuracy

Field data	Classification data		Quantity
	Mangrove	Non-mangrove	
Mangrove	17	8	25
Non-mangrove	1	24	25
Quantity	18	32	50

The accuracy test results from 25 mangrove points and 25 non-mangrove points in Table 4. show quite good results. *The overall accuracy* was obtained 82% and *the Kappa coefficient* was obtained with a value of 0.64. The *overall accuracy* value indicates that the model managed to correctly classify 82% of pixels. This is evidence that MVI is effective in distinguishing mangroves from non-mangrove areas in coastal areas, but it still needs to be improved due to the potential for mixed pixels or environmental factors such as waterlogging. The results of a similar study conducted by Baloloy *et al.* (2020) in the Philippines showed an overall accuracy value of 92% using MVI. Meanwhile, the *Kappa coefficient* of 0.64 confirms that mangrove mapping using MVI is quite consistent. The accuracy results can depend on the number of classes mapped (Mastu *et al.*, 2018). The results of this accuracy test indicate that the mangrove cover map is quite good and can be scientifically accounted for.

CONCLUSION

This study succeeded in analyzing the spatio-temporal dynamics of mangrove cover in Rembang District which includes Pasarbanggi, Tireman, and Kabongan Lor Villages for the last 40 years (1985-2025) using geospatial analysis based on Landsat 5 and Sentinel-2A satellite image processing using the MVI method. The results of the study can be concluded as follows.

1. The area of mangrove cover in Rembang District for a period of 40 years has experienced very significant fluctuations. There was a decrease in mangrove cover area by 67.93%, from 26.89 ha (1985) to 8.62 ha (2005). Massive mangrove rehabilitation efforts have increased the mangrove cover area by 339.56%, from 8.62 ha (2005) to 37.89 ha (2025) and makes Rembang one of the successful examples of mangrove rehabilitation on the northern coast of Central Java.
2. The dynamics of mangrove cover show a clear pattern, where:
 - a. From 1985 to 2005, there was heavy degradation due to the massive conversion of mangrove land into salt ponds and fish ponds.
 - b. 2005-2016 was an explosive recovery phase with the addition of mangroves of 23.73 ha as a result of the success of the rehabilitation program.
 - c. 2016-2025 will be a phase of sustainable recovery and stabilization with an increase in the total mangrove cover area of 10.87 ha, characterized by an increase in the high cover class from 17.39 ha to 27.40 ha (36.53%).

The success of mangrove restoration in Rembang to reach 37.89 ha by 2025 indicates that rehabilitation activities involving many related and community-based stakeholders, intensive planting, and land conversion control are able to significantly restore ecological functions, abrasion resistance, and mangrove ecosystem services.

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